Moist and Boundary Layer Physics for Mesoscale Modeling

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LONG-TERM GOAL

Improve the understanding of cloud and boundary layer processes within the littoral through the use of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) and relevant observations. Improve the moist and boundary layer physics schemes used in COAMPS based on knowledge gained through extensive testing and verification of high-resolution (1-20 km horizontal grid spacing) numerical simulations in the littoral.

OBJECTIVES

Develop scientific knowledge on the dynamics of boundary layer processes and stratiform, coastal orographic, and meso-convective cloud systems. Evaluate the impact of these processes on regional-scale forecasts and weapon and sensor systems used by the Fleet. Evaluate model biases in moisture, precipitation, and cloud coverage forecasts in regions of complex coastal orography using case study analyses and real-time forecasts of observed events. Use explicit cloud simulations to test and make improvements in the computationally efficient bulk microphysical and cumulus parameterization schemes currently used in high-resolution (1-20 km horizontal grid spacing) COAMPS forecasts. Complete term-by-term analyses of the boundary layer forcing terms in COAMPS and assess model biases in boundary layer structure such as predicted boundary layer depth, vertical stability and moisture profiles, and electromagnetic/electro-optical (EM/EO) characteristics. Improve boundary layer physics schemes used in COAMPS based on testing and model verification with relevant observational and numerical databases.

APPROACH

Tests of the cumulus parameterization and bulk microphysical schemes will be made for a variety of geographical and meteorological conditions to gauge the model's performance against verifying data for a broad spectrum of observed and modeled stratiform and meso-convective cloud systems. Results from explicit cloud simulations will be used to gauge the quality of and make improvements in the computationally efficient bulk microphysical and cumulus parameterization schemes currently used in

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14. ABSTRACT
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high-resolution COAMPS forecasts. For the boundary layer processes, we will utilize special data sets that permit validation of individual terms that are parameterized within COAMPS. All terms contributing to the surface energy budgets of momentum, heat, and moisture will be examined and test of new approaches will be conducted where warranted. The COAMPS parameterizations above the surface layer will also be assessed using field experimental data sets; improvements will be sought as necessary.

WORK COMPLETED

The Coupled Ocean-Atmosphere Response Experiment (COARE) algorithm for computing over-water surface fluxes, developed as a part of an international effort, was modified and tested within COAMPS as a potential upgrade to the current Louis surface flux parameterization. As part of this new scheme, a novel approach for rapidly computing the complex surface layer stability functions was developed, tested, and validated, and a journal article has been prepared for submission. The COARE algorithm is now scheduled for operational implementation within COAMPS. Extensive evaluation of COAMPS marine boundary layer forecasts of microwave refractivity were conducted using data from the VOCAR field experiment. The model's duct heights are biased too shallow, its duct strengths are biased too weak, and its duct thicknesses tend to be too large. To better isolate these biases, a series of 1-D COAMPS runs have been initiated comparing results with many other mesoscale models and Large-Eddy Simulation (LES) models on standardized cases.

A new version of the 1983 Rutledge and Hobbs (RH83) explicit moist physics scheme is nearing completion and will be transitioned to COAMPS at the completion of this work unit. Major upgrades were made to the scheme's underlying physics and to correct problems with the lack of water mass and energy conservation resulting from the original adjustment to saturation procedure. New physics were added to account for: (i) secondary ice crystal multiplication processes, (ii) the development of graupel, (iii) more advanced nucleation of cloud water and pristine ice, (iv) differences between continental and marine cloud structure (accomplished by adding representative values for cloud condensation nuclei) and (v) additional conversions between the ice and liquid phases which were required to prevent the presence of liquid water at temperatures below -40C.

Work also continued on the calculation of the mixing coefficients in mixed-phase clouds. This work extends the liquid phase calculations initially derived by Klemp and Wilhelmson (1978). The primary motivations for this work are to: (i) reduce the tendency of the implicit mixing scheme in COAMPS to spread condensate well into the surrounding clear air environment and (ii) improve the representation of the buoyancy flux in mixed phase clouds. Testing is currently being carried out using explicit simulations of idealized "2-D" stratus clouds and on a real data case associated with extreme turbulence. The work will also incorporate and extend the results Cuijpers and Duynkerke (1993) to include the impact of the ice phase in the calculation of the buoyancy flux.

RESULTS

The following two figures illustrate the changes in explicitly resolved (horizontal grid spacing of 2 km) storm structure that arise between the original RH83 scheme and the modified microphysical scheme. The deep convective plumes illustrated in these figures were initialized in identical, highly idealized, sheared environments by adding a specified heating function during the first 1200 seconds of the

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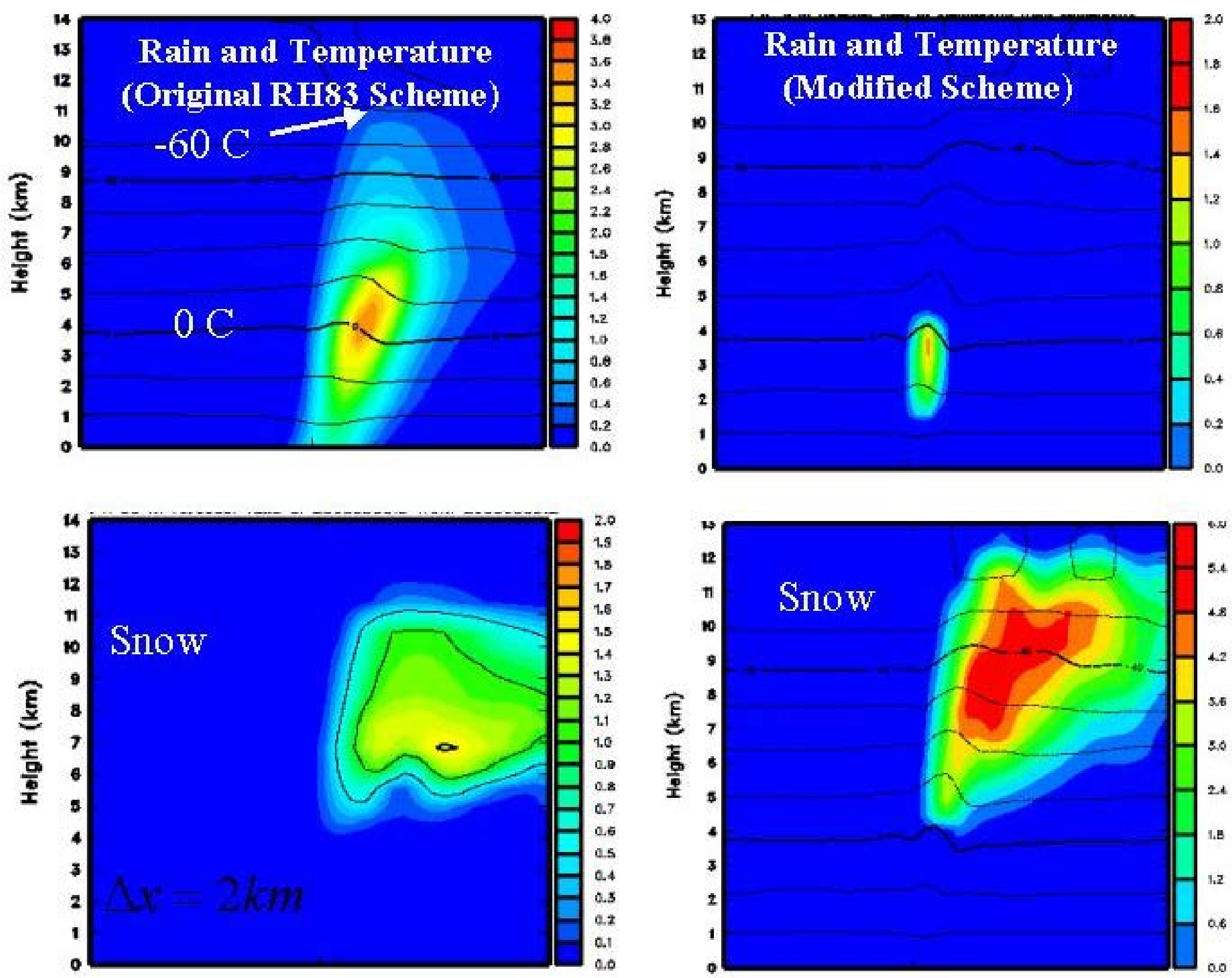
simulation. The most notable differences between the two figures are the changes in the rainwater snow fields. The upper left panel shows the upward transport of the rainwater to extremely cold temperatures (-60 C) within the convective-scale updraft. While one expects the existence of some super-cooled liquid water in real storms, the amount of rain converting to the ice phase is generally thought to occur exponentially with the degree of supercooling (Bigg, 1953) and is typically not observed well below the homogeneous freezing temperature of –40 C. The unrealistic rainwater field would have a detrimental effect on the storm dynamics by neglecting the important latent heat of fusion that can be released within the updraft in the simulated storm. It would also hinder attempts to use radar data assimilation techniques to retrieve more realistic cloud structures due to the poor initial guess of the vertical velocity and condensate fields. The modified scheme shows a much more robust snow field (lower right panel) due to the added conversions from rainwater and cloud water to snow. These conversions lead to a more powerful updraft as evidenced by the higher cloud tops. The conversion to rain in the new scheme was adapted from the RH84 graupel scheme. While the results suggest an improvement in the overall structure of the simulated system, we are not yet completely satisfied by the fact the most of the rain is converted just below freezing. We are in the process of testing the formulation by Bigg (1953) to see if a more gradual transition is realized.



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IMPACT/APPLICATIONS

The littoral is considered the most important and challenging region for conducting military operations. Part of the challenge stems from the need for accurate prediction of the weather parameters (such as cloud ceiling, visibility, EM and EO conditions, etc.) that impact naval forces in the littoral.

The desire from the fleet for detailed forecasts of clouds and boundary layer parameters in the littoral is leading to mesoscale model simulations run at increasingly fine horizontal resolution (model grid spacing on the order of 1-20 km). It is at such scales where the proper treatment of boundary layer processes and stratiform and meso-convective cloud systems play an increasing role in the overall accuracy of the short-term (0-36 hour) mesoscale forecasts used in the Strike Warfare and general Naval operation decision making process. Currently there is no deterministic method for providing or quantifying the overall accuracy of the cloud and boundary layer parameter forecasts to the tactical decision makers. This project addresses these needs through a greater understanding of the relevant cloud and boundary layer dynamics and through evaluation of the Coupled Oceanic and Atmospheric Mesoscale Prediction System (COAMPS) moisture and boundary layer schemes that will be used to derive the required atmospheric tactical parameters.

TRANSITIONS

Improvements to COAMPS that result from this research will transition to 6.4 (PE 0603207N, task X-0513, SPAWAR PMW-185) for incorporation into the operational COAMPS forecast model.

RELATED PROJECTS

Related NRL projects are NRL BE 35-2-18, Mesoscale Modeling of the Atmosphere and Aerosols and NRL BE 033-03-45, a 6.1 new start in Atmospheric Cloud, Moisture, and Aerosol Physics. The related 6.4 projects under PE 0603207N, X2342 (SPAWAR, PMW-185) are STAFC (on-Scene Tactical Atmospheric Forecast Capability) and Small-scale Atmospheric Models.

PUBLICATIONS

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